

## CLAIMS

The invention claimed is:

1. A method of forming a material over a substrate comprising utilization of at least one iteration an ALD-type pulse sequence of  $M_1$ - $M_2$ -R, where  $M_1$  is a first metal-containing precursor comprising a first metal,  $M_2$  is a second metal-containing precursor comprising a second metal different from the first metal, and R is a reactant which reacts with one or both of the first and second metals.

2. The method of claim 1 wherein at least one of the first and second metals is selected from the group consisting of aluminum, hafnium, lanthanides, niobium, tantalum, titanium, yttrium and zirconium.

3. The method of claim 1 wherein both of the first and second metals are selected from the group consisting of aluminum, hafnium, lanthanides, niobium, tantalum, titanium, yttrium and zirconium.

4. The method of claim 1 wherein the first and second metals are aluminum and hafnium, respectively.

5. The method of claim 1 wherein the first and second metals are hafnium and aluminum, respectively.

6. The method of claim 1 wherein the first and second metals are aluminum and titanium, respectively.

7. The method of claim 1 wherein the first and second metals are titanium and aluminum, respectively.

8. The method of claim 1 wherein the pulse sequence is  $M_1-M_2-M_1-R$ .

9. The method of claim 1 wherein the pulse sequence is  $(M_1-M_2-...M_n)-R$ , where  $n$  is greater than or equal to 3.

10. The method of claim 1 wherein:  
the first metal is hafnium,  
the second metal is aluminum,  
 $M_1$  is tetrakis-methylethylamido hafnium (TMEAH), and  
 $M_2$  is trimethyl aluminum (TMA).
  
11. The method of claim 1 wherein:  
the first metal is hafnium,  
the second metal is aluminum,  
 $M_1$  is tetrakis-dimethylamino hafnium (TDMAH), and  
 $M_2$  is trimethyl aluminum (TMA).
  
12. The method of claim 1 wherein:  
the first metal is aluminum,  
the second metal is hafnium,  
 $M_1$  is trimethyl aluminum (TMA), and  
 $M_2$  is tetrakis-methylethylamido hafnium (TMEAH).

13. The method of claim 1 wherein:

the first metal is aluminum,

the second metal is hafnium,

M<sub>1</sub> is trimethyl aluminum (TMA), and

M<sub>2</sub> is tetrakis-dimethylamino hafnium (DMAH).

14. The method of claim 1 wherein:

the first metal is aluminum,

the second metal is hafnium,

R is ozone (O<sub>3</sub>),

M<sub>1</sub> is trimethyl aluminum (TMA),

M<sub>2</sub> is tetrakis-methylethylamido hafnium (TMEAH), and

and the pulse sequence is TMA-(TMEAH-O<sub>3</sub>)<sub>x</sub>, where x is an integer greater than zero.

15. The method of claim 1 wherein:
- the first metal is aluminum,
  - the second metal is hafnium,
  - R is ozone ( $O_3$ ),
  - $M_1$  is trimethyl aluminum (TMA),
  - $M_2$  is tetrakis-dimethylamino hafnium (TDMAH), and
  - and the pulse sequence is  $TMA-(TDMAH-O_3)_x$ , where x is an integer greater than zero.
16. The method of claim 1 further comprising, after the R in the pulse sequence, utilizing at least one iteration of the pulse sequence of  $M_1$ -R.
17. The method of claim 1 further comprising, after the R in the pulse sequence, utilizing at least one iteration of the pulse sequence of  $M_2$ -R.
18. The method of claim 1 wherein R reacts with both of the first and second metals.

19. The method of claim 1 wherein R is selected from the group consisting of silicon, nitrogen and oxygen; and wherein the first and second metals are selected from the group consisting of aluminum, hafnium and titanium.

20. A method of forming a material over a substrate, comprising:  
placing the substrate within a reaction chamber and, while the  
substrate is within the chamber, performing at least one iteration of the following  
sequence:

providing a first precursor within the reaction chamber and  
chemisorbing a first species from the first precursor onto the  
substrate;

removing substantially all of the first precursor from within the  
reaction chamber;

providing a second precursor within the reaction chamber and  
sorbing a second species from the second precursor in contact with  
the first species, the second precursor having a different composition  
than the first precursor;

removing substantially all of the second precursor from within  
the reaction chamber;

providing a reactant within the reaction chamber and reacting  
said reactant with at least one of the first and second species; and

removing substantially all of the reactant from within the  
reaction chamber.

21. The method of claim 20 wherein at least one of the first and second species does not comprise metal.

22. The method of claim 20 wherein at least one of the first and second species comprises Si.

23. The method of claim 20 wherein at least one of the first and second species comprises Si.

24. The method of claim 20 wherein one of the first and second species comprises Si and the other comprises Ge.

25. The method of claim 20 wherein the first species comprises a first metal, the second species comprises a second metal different from the first metal, and said first and second metals are selected from the group consisting of aluminum, hafnium, lanthanides, niobium, tantalum, titanium, yttrium and zirconium.



26. The method of claim 20 wherein one of the first and second species comprises hafnium and the other of the first and second species comprises aluminum.

27. The method of claim 20 wherein one of the first and second species comprises titanium and the other of the first and second species comprises aluminum.

28. The method of claim 20 wherein the first precursor is trimethyl aluminum and the second precursor is tetrakis methylethylamido hafnium.

29. The method of claim 28 wherein the first species comprises aluminum, the second species comprises hafnium, the reactant comprises oxygen, and the reacting forms aluminum oxide and hafnium oxide.

30. The method of claim 29 wherein the reactant is O<sub>3</sub>.

31. The method of claim 28 wherein the first species comprises aluminum, the second species comprises hafnium, the reactant comprises nitrogen, and the reacting forms aluminum nitride and hafnium nitride.

32. The method of claim 31 wherein the reactant includes one or more of ammonia, hydrazine, monomethyl hydrazine and dimethyl hydrazine.

33. The method of claim 28 wherein the first species comprises aluminum, the second species comprises hafnium, the reactant comprises silicon, and the reacting forms aluminum silicide and hafnium silicide.

34. The method of claim 20 wherein the first precursor is tetrakis methylethylamido hafnium and the second precursor is trimethyl aluminum.

35. The method of claim 34 wherein the first species comprises hafnium, the second species comprises aluminum, the reactant comprises oxygen, and the reacting forms aluminum oxide and hafnium oxide.

36. The method of claim 35 wherein the reactant is  $O_3$ .

37. The method of claim 34 wherein the first species comprises hafnium, the second species comprises aluminum, the reactant comprises nitrogen, and the reacting forms aluminum nitride and hafnium nitride.

38. The method of claim 37 wherein the reactant includes one or more of ammonia, hydrazine, monomethyl hydrazine and dimethyl hydrazine.

39. The method of claim 34 wherein the first species comprises hafnium, the second species comprises aluminum, the reactant comprises silicon, and the reacting forms aluminum silicide and hafnium silicide.

40. The method of claim 20 wherein the first precursor is  $TiCl_4$  and the second precursor is trimethyl aluminum.

41. The method of claim 40 wherein the first species comprises titanium, the second species comprises aluminum, the reactant comprises nitrogen, and the reacting forms aluminum nitride and titanium nitride.

42. The method of claim 41 wherein the reactant includes one or more of ammonia, hydrazine, monomethyl hydrazine and dimethyl hydrazine.

43. The method of claim 20 wherein the first precursor is trimethyl aluminum and the second precursor is  $\text{TiCl}_4$ .

44. The method of claim 43 wherein the first species comprises aluminum, the second species comprises titanium, the reactant comprises nitrogen, and the reacting forms aluminum nitride and titanium nitride.

45. The method of claim 44 wherein the reactant includes one or more of ammonia, hydrazine, monomethyl hydrazine and dimethyl hydrazine.

46. The method of claim 20 wherein the substrate includes a first capacitor electrode, wherein the at least one iteration forms a dielectric material over the first capacitor electrode, and further comprising forming a second capacitor electrode over the dielectric material and capacitively connected with the first capacitor electrode.

47. The method of claim 46 wherein the dielectric material comprises hafnium oxide and aluminum oxide.

48. The method of claim 20 wherein the at least one iteration forms a metal nitride composition, and further comprising:

forming a pair of capacitor electrodes and a dielectric material over the substrate, the capacitor electrodes being separated from one another by the dielectric material; and

incorporating the metal nitride composition into one of the capacitor electrodes.

49. The method of claim 48 wherein the metal nitride composition comprises aluminum nitride and titanium nitride.

50. A method of forming a material over a substrate, comprising:  
placing the substrate within a chamber; and  
while the substrate is within the chamber, performing at least one iteration of a sequence consisting of the following steps:  
  
providing two or more different metal-containing precursors within the chamber at different and substantially non-overlapping times relative to one another to form a material over the substrate that comprises metals from said two or more precursors, at least two of the metals being different from one another; and  
exposing the material to one or more reactants, at least one of said reactants interacting with at least one of the of the metals to change the composition of the material.
51. The method of claim 50 wherein said at least two metals include one or more of aluminum, hafnium, lanthanides, niobium, tantalum, titanium, yttrium and zirconium.
52. The method of claim 50 wherein one of said at least two metals is hafnium and another of said at least two metals is aluminum.

53. The method of claim 52 wherein the hafnium is provided before the aluminum.

54. The method of claim 52 wherein the aluminum is provided before the hafnium.

55. The method of claim 52 wherein said at least one of the reactants comprises oxygen, and wherein the interaction of the oxygen with one or more metals of the material changes the composition of the material to comprise at least one of hafnium oxide and aluminum oxide.

56. The method of claim 52 wherein said at least one of the reactants comprises oxygen, and wherein the interaction of the oxygen with the aluminum and hafnium changes the composition of the material to a dielectric material comprising hafnium oxide and aluminum oxide.

57. The method of claim 52 wherein said at least one of the reactants comprises nitrogen, and wherein the interaction of the nitrogen with one or more metals of the material changes the composition of the material to comprise at least one of hafnium nitride and aluminum nitride.

58. The method of claim 52 wherein said at least one of the reactants comprises nitrogen, and wherein the interaction of the nitrogen with the aluminum and hafnium changes the composition of the material to comprise hafnium nitride and aluminum nitride.

59. The method of claim 52 wherein said at least one of the reactants comprises silicon, and wherein the interaction of the silicon with one or more metals of the material changes the composition of the material to comprise at least one of hafnium silicide and aluminum silicide.

60. The method of claim 52 wherein said at least one of the reactants comprises silicon, and wherein the interaction of the silicon with the aluminum and hafnium changes the composition of the material to comprise hafnium silicide and aluminum silicide.



61. The method of claim 50 wherein one of said at least two metals is titanium and another of said at least two metals is aluminum.

62. The method of claim 61 wherein said at least one of the reactants comprises nitrogen, and wherein the interaction of the nitrogen with one or more metals of the material changes the composition of the material to comprise at least one of titanium nitride and aluminum nitride.

63. The method of claim 61 wherein said at least one of the reactants comprises nitrogen, and wherein the interaction of the nitrogen with the titanium and aluminum changes the composition of the material to comprise titanium nitride and aluminum nitride.

64. The method of claim 50 wherein the substrate includes a first capacitor electrode, wherein the at least one iteration forms a dielectric material over the first capacitor electrode, and further comprising forming a second capacitor electrode over the dielectric material and capacitively connected with the first capacitor electrode.

65. The method of claim 64 wherein the dielectric material comprises hafnium oxide and aluminum oxide.

66. A method of forming a material over a substrate, comprising:  
placing the substrate within a reaction chamber and, while the substrate is within the chamber, performing at least one iteration of the following sequence:

providing a first precursor within the reaction chamber and depositing a first component of the material from the first precursor, the first component comprising a first metal and forming a substantially saturated monolayer over the substrate;

removing substantially all of the first precursor from within the reaction chamber;

providing a second precursor within the reaction chamber and depositing a second component of the material from the second precursor, the second component comprising a second metal different from the first metal, the second component integrating with the substantially saturated monolayer of the first component;

removing substantially all of the second precursor from within the reaction chamber; and

exposing the material comprising the first and second components to one or more reactants, at least one of said reactants interacting with at least one of the of the first and second components to change the composition of the material.

67. The method of claim 66 wherein at least one of the first and second metals is selected from the group consisting of aluminum, hafnium, lanthanides, niobium, tantalum, titanium, yttrium and zirconium.

68. The method of claim 66 wherein both of the first and second metals are selected from the group consisting of aluminum, hafnium, lanthanides, niobium, tantalum, titanium, yttrium and zirconium.

69. The method of claim 66 wherein one of the first and second metals is hafnium and the other is aluminum.

70. The method of claim 69 wherein one of the first and second precursors is tetrakis methylethylamido hafnium and the other is trimethyl aluminum.

71. The method of claim 69 wherein the first metal is hafnium.

72. The method of claim 69 wherein the first metal is aluminum.

73. The method of claim 69 wherein said one or more reactants include an oxygen-containing reactant, and wherein said change in composition of the material includes formation of oxide from at least one of the first and second metals.

74. The method of claim 73 wherein said change in composition of the material includes formation of oxide from both of the first and second metals.

75. The method of claim 69 wherein said one or more reactants include a nitrogen-containing reactant, and wherein said change in composition of the material includes formation of nitride from at least one of the first and second metals.

76. The method of claim 75 wherein said change in composition of the material includes formation of nitride from both of the first and second metals.

77. The method of claim 69 wherein said one or more reactants include a silicon-containing reactant, and wherein said change in composition of the material includes formation of silicide from at least one of the first and second metals.

78. The method of claim 77 wherein said change in composition of the material includes formation of silicide from both of the first and second metals.

79. The method of claim 66 wherein one of the first and second metals is titanium and the other is aluminum.

80. The method of claim 79 wherein one of the first and precursors is  $\text{TiCl}_4$  and the other is trimethyl aluminum.

81. The method of claim 79 wherein said one or more reactants include a nitrogen-containing reactant, and wherein said change in composition of the material includes formation of nitride from at least one of the first and second metals.

82. The method of claim 81 wherein said change in composition of the material includes formation of nitride from both of the first and second metals.

83. The method of claim 66 wherein the substrate includes a first capacitor electrode, wherein the at least one iteration forms a dielectric material over the first capacitor electrode, and further comprising forming a second capacitor electrode over the dielectric material and capacitively connected with the first capacitor electrode.

84. The method of claim 83 wherein the dielectric material comprises hafnium oxide and aluminum oxide.

85. The method of claim 66 wherein the at least one iteration forms a metal nitride composition, and further comprising:

forming a pair of capacitor electrodes and a dielectric material over the substrate, the capacitor electrodes being separated from one another by the dielectric material; and

incorporating the metal nitride composition into one of the capacitor electrodes.

86. The method of claim 85 wherein the metal nitride composition comprises aluminum nitride and titanium nitride.